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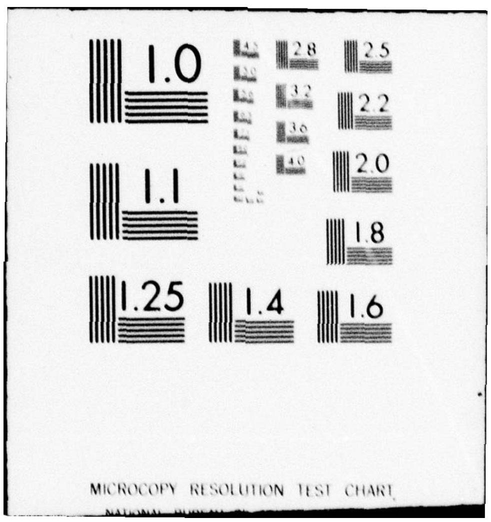
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NRL Memorandum Report 3769

Ionospheric Modification: An Initial Report on Artificially Created Equatorial Spread F

S. L. OSSAKOW, S. T. ZALESAK, and B. E. MCDONALD

Geophysical and Plasma Dynamics Branch
Plasma Physics Division

May 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A numerical simulation code for investigating equatorial Spread F in the collisional Rayleigh-Taylor regime is utilized to follow the evolution of artificial plasma density depletions injected into the bottomside nighttime equatorial F region. The 70 km diameter hole rapidly rises and steepens, forming plasma density enhancements at altitudes below the rising hole. The distribution of enhancements and depletions is similar to natural equatorial Spread F phenomena, except it occurs on a much faster time scale.

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IONOSPHERIC MODIFICATION:
AN INITIAL REPORT ON ARTIFICIALLY CREATED EQUATORIAL SPREAD F

I. Introduction

Since the discovery of a large dropout (ionospheric hole) in the ionospheric total electron content during the launch of NASA's Skylab (Mendillo et al., 1975 a,b) much investigation has gone into the controlled artificial production of such holes or plasma density depletions in the F region ionosphere (Bernhardt et al., 1975; Bernhardt, 1976; Bernhardt and da Rosa, 1977; Mendillo and Forbes, 1978; Pongratz et al., 1978; see also Trans. Am. Geophys. Un., 58, 454-455, 1977, Spring Meeting Special Session on "Artificially Created Holes in the Ionosphere"). Typically investigators have focused on the chemical release of H_2O, H_2 or high explosives. These contain molecular species which react with ionospheric O^+ in such a manner that the O^+ loss rate due to these reactions is several orders of magnitude faster than natural ionospheric loss rates for O^+ (Mendillo et al., 1975 a,b; Bernhardt, 1976). Recently, Pongratz et al. [1978] conducted two high explosive (88kgm mixture of nitromethane and ammonium nitrate) F region chemical releases (260 and 280 km altitude), codenamed Lagopedo, over the Hawaiian Islands (midlatitude) and formed a hole ($\sim$ 100 km in diameter) via the predicted chemical processes.

Note: Manuscript submitted March 22, 1978.

Within the context of artificial hole formation much of the theoretical work to date (Mendillo et al., 1975 b; Bernhardt, 1976; Pongratz et al., 1978) has centered on the complicated chemical reactions and molecular diffusion equations for producing these holes (e.g., electrodynamic forces, such as polarization electric fields, on the ions or electrons are not considered). In the past few years, experimental (Kelly et al., 1976; McClure et al.,1977) and numerical simulation studies (Scannapieco and Ossakow, 1976) have observed (under appropriate conditions) the formation of natural, rising plasma density depletions (holes or bubbles) in the equatorial Spread F ionosphere. In the present paper we wish to perform a marriage between the two studies and examine the behavior of a large plasma density depletion (hole) artificially injected into the bottom-side nighttime equatorial F region ionosphere.

II. Theoretical Model and Numerical Simulation Studies

In the present simplified model we will take the approach that the large hole has already been created and thus represents a new initial condition for our previous nonlinear numerical simulation equatorial Spread F studies [Scannapieco and Ossakow, 1976; Ossakow et al., 1978 a,b]. In this way we do not follow the chemical kinetics of the actual hole making process, rather we follow the evolution of the hole after it has been produced. Pongratz et al. [1978] noted that the entire hole in Lagopedo was produced in less than 5 minutes and Sjolander et al. [1978] noted, using rocket in situ ion mass spectrometer measurements during Lagopedo, that the dominant ion in

the artificially created hole was O^+. Thus, we are able to utilize the two dimensional (perpendicular to the magnetic field, $\underline{B}$) numerical simulation code developed for natural equatorial Spread F studies in the collisional Rayleigh-Taylor regime, which is represented by the following equations (see Scannapieco and Ossakow, 1976; Ossakow et al., 1978 a,b)

$$\frac{\partial n}{\partial t} - \frac{c}{B} (\nabla\phi_1 \times \hat{z}) \cdot \nabla n = -\nu_R (n - n_o) \qquad (1)$$

$$\nabla \cdot (\nu_{in} n \nabla \phi_1) = \frac{B}{c} (\underline{g} \times \hat{z}) \cdot \nabla n \qquad (2)$$

where n is the electron density (n_o refers to the background equilibrium density; $n \equiv n_o + n_1$), ϕ_1 is the polorization (induced) potential, ν_R is the usual (used in natural Spread F studies) ionospheric recombination rate (see Fig. 1), ν_{in} is the usual ion-neutral collision frequency, $\underline{g}$ is gravity (pointing in the -y direction), $\hat{z} = \underline{B}/|B|$ and ∇ refers to the x and y directions. In our simulations realistic altitude profiles of ν_{in} and ν_R (see Fig. 1) and n_o (see Fig. 2) have been used.

The numerical simulation plane coincided with the equatorial plane spanning an altitude (y) range from 172 to 452 km in one case and 252 to 532 km in the other case (both with Δy = 2 km) with an east-west (x) extent of 200 km (Δx = 5 km). The system of eqns. (1) and (2) was initialized as follows

$$n/n_o = \begin{cases} 0.03 \;, \; r-r_o \leq 15 \text{ km} \\ \exp[\alpha(r-r_o-15)^3] - 0.97 \;, \; 15 \text{ km} < r-r_o \leq 35 \text{ km} \\ 1.0, \; r-r_o > 35 \text{ km} \end{cases} \qquad (3)$$

where $\alpha = \ln(1.97)/(20)^3$. This provided a constant 97% depletion over a central 30 km of the hole and the depletion decreased to ambient density over a 20 km extent on each side (total extent of bubble was 70 km). The thickness of the hole at half depletion was ~ 63 km (see for example Pongratz et al., 1978). The results of a simulation with r_o corresponding to $x_o = 0$, $y_o = 300$ km, i.e., release altitude = 300 km, are shown in Figs. 2-5, which depict contour plots of n/n_o (or equivalently n_1/n_o) at t = 0, 500, 1000, and 2000 sec. The t = 0 frame shows the initial state after the hole has been formed by chemical processes. At t = 500 sec the hole has begun to steepen on its topside as it rises toward the F peak (altitude = 354 km). This corresponds to a rise velocity ~ 28 m/sec. We note that the initial hole is no longer circular and plasma density enhancements are forming to the sides of the bubble (hole). As the initial depletion rises on the bottomside it displaces regions of higher density which fall to lower altitudes creating enhancements. At t = 1000 sec the top of the bubble is at the F peak and the enhancements are getting larger. This should be contrasted with the natural Spread F developing bubble, in this ionospheric profile, which took ~ 8000 sec to reach the peak (see Scannapieco and Ossakow, 1976; Ossakow et al., 1978b). At t = 2000 sec the hole is well past the

peak and has bifurcated on its topside. This is similar to barium cloud striation bifurcation phenomena (see Zabusky et al., 1973; Ossakow et al., 1977) and would lead to smaller scale structures if the present simulation had more resolution. The hole is now accompanied by large enhancements and the enhancements in turn are forcing depletions to lower altitudes. This picture is far different from the initial circular hole at $t = 0$. This figure shows a wide-spread rapid equatorial Spread F condition.

Figures 6-9 exhibit the results for an artificial depletion released at 380 km altitude ($x_o = 0$, $y_o = 380$ km) in an ionosphere with the altitude of the F peak equal to 434 km. In this case the time evolution of the hole is much more rapid. For example, between $t = 0$ and 50 sec the hole is rising with a velocity ~ 88 m/sec. The initial rise velocity, here and in the previous case, is consistent with a bubble rise velocity given by (Ossakow and Chaturvedi, 1978) $V_B = (g/\nu_{in})\, f\, (n_1/n_o)$, where $f\, (n_1/n_o)$ is an increasing function of the percentage depletion, n_1/n_o, and dependent on bubble shape. In particular f corresponds here to a circular-like shape. The case depicted in Figs. 6-9 is also to be contrasted to the natural Spread F case in this geometry where a bubble took ~ 1000 sec to reach the F peak.

III. Concluding Remarks

We have presented numerical simulation results, in the collisional Rayleigh-Taylor regime, of artificial depletions injected into the bottomside nighttime equatorial F region. It has been shown

that such depletions, while they steepen and rise, will cause plasma density enhancements to be formed. The entire final picture is similar to natural equatorial Spread F numerical simulation phenomena except that by artificial injection it occurs on a much faster time scale.

Acknowledgement

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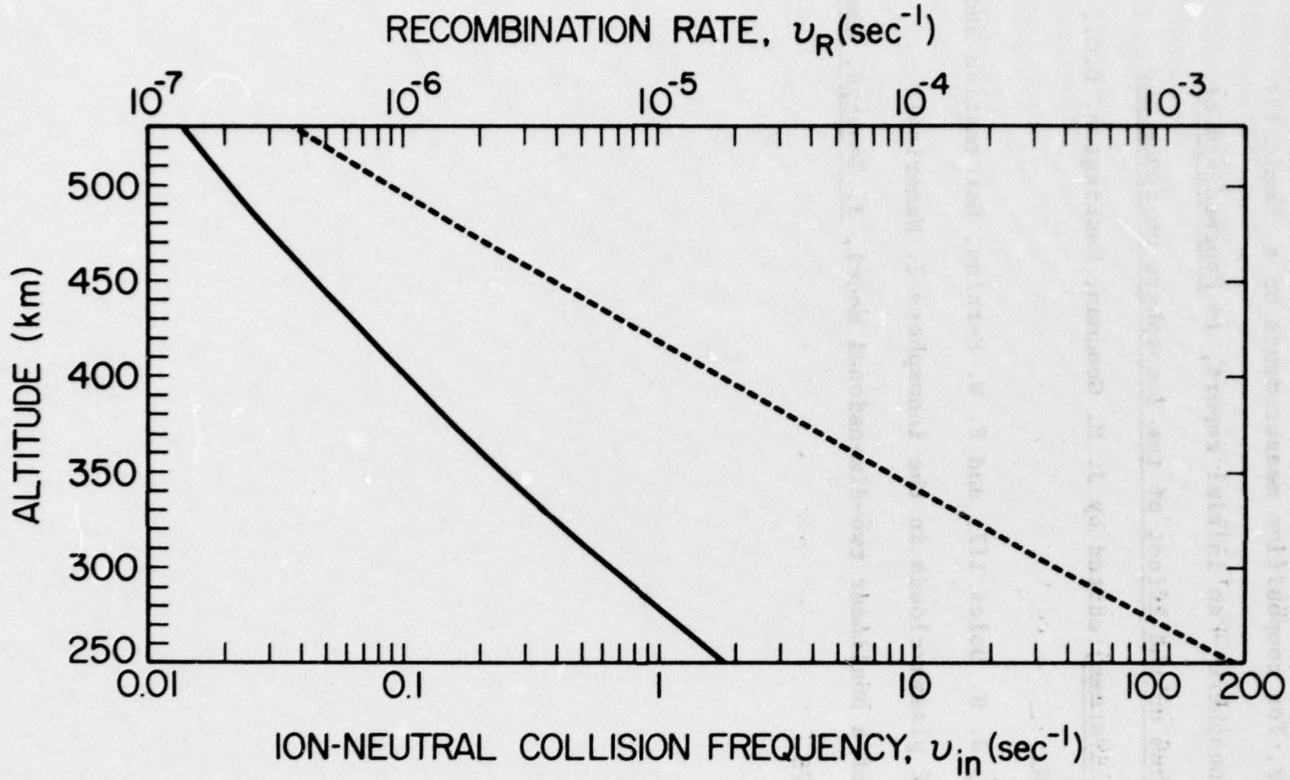

Fig. 1 — Values of ion-neutral collision frequency (solid curve), ν_{in}, and recombination rate (dashed curve), ν_R, as a function of altitude used in the artificial hole injection simulations.

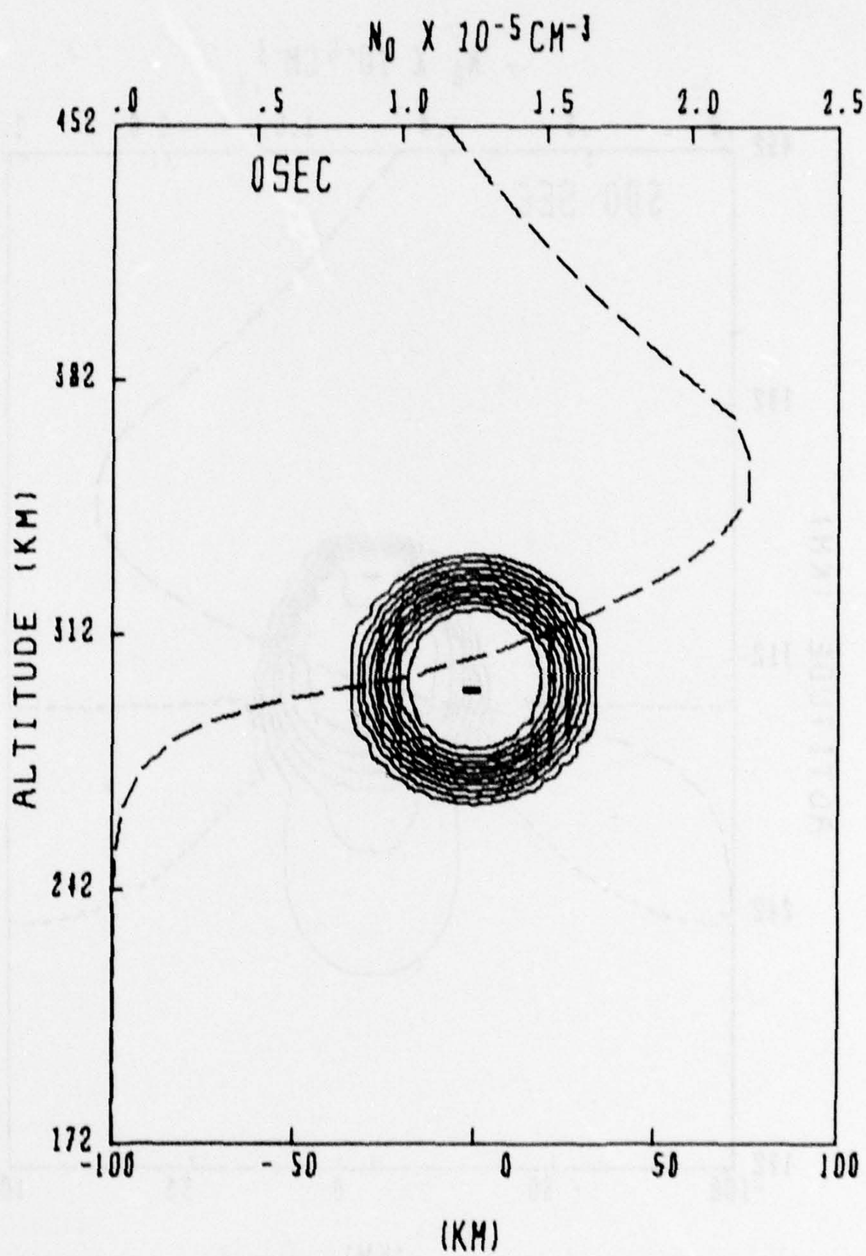

Fig. 2 — Contour plots of constant n_1/n_0 at $t = 0$ sec (initial condition). The circular contours represent the artificial depletion (-) such that the outermost contour is a 16% depletion and the innermost is a 96% depletion (inside this contour is a constant 97% depletion). The large dashed curve represents a plot of the ambient electron number density (values on upper horizontal axis), n_0, as a function of altitude. The vertical (y) axis represents altitude, the lower horizontal (x) axis east-west range, and the ambient magnetic field is out of the figure (z).

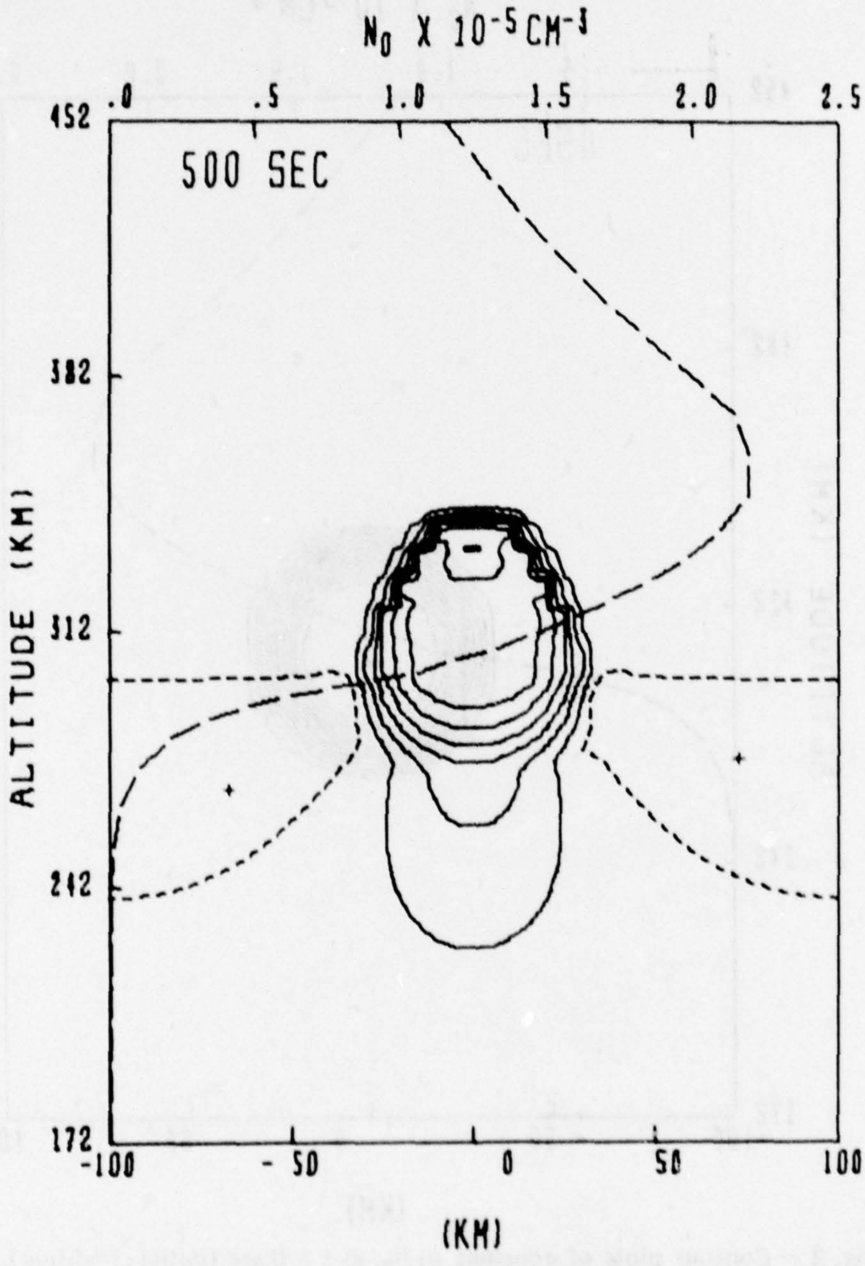

Fig. 3 — Same as Fig. (1), except t = 500 sec. The smaller dashed contours are contours of constant n_1/n_0 for plasma density enhancements (+). The enhancement contour represents a 19% enhancement.

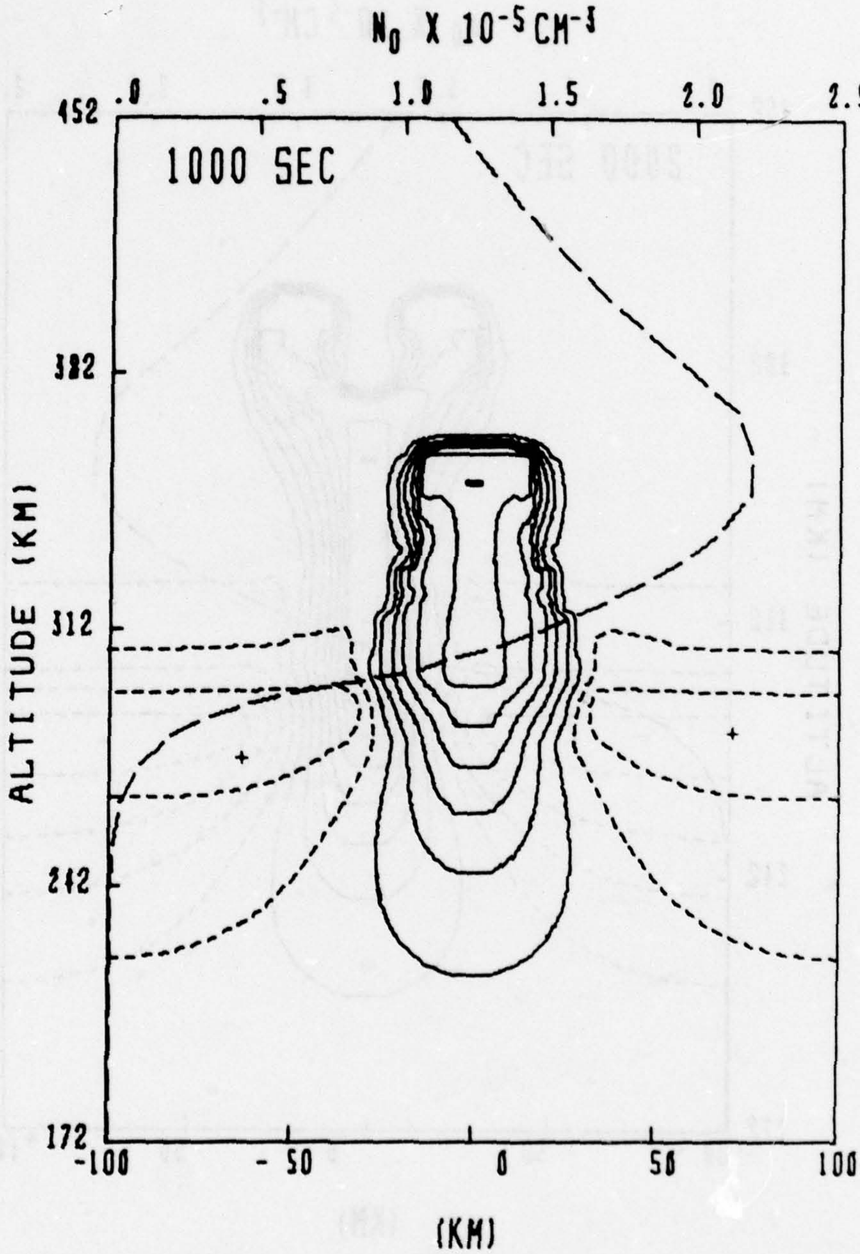

Fig. 4 — Same as Fig. 2, except t = 1000 sec. The inner enhancement contour represents a 68% enhancement.

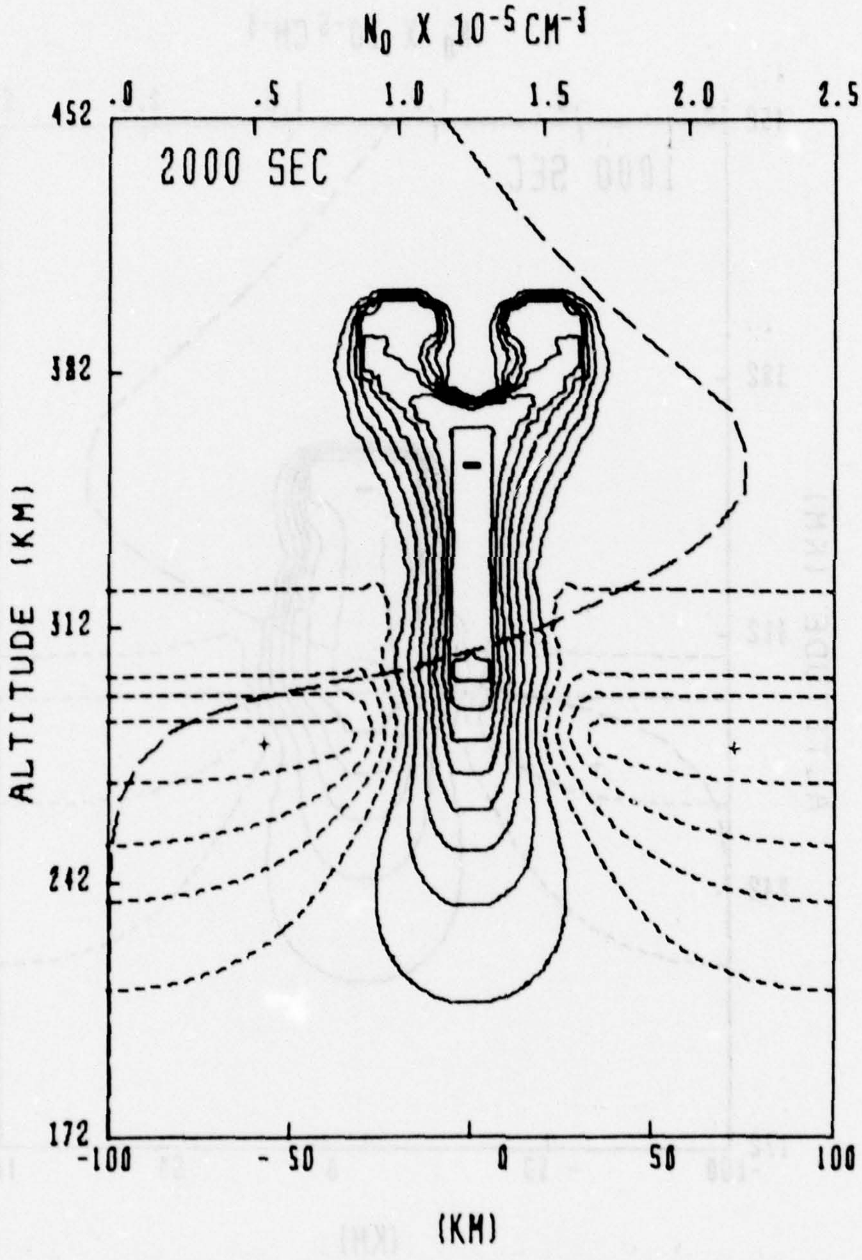

Fig. 5 — Same as Fig. 2, except t = 2000 sec. The inner enhancement contour represents a 236% enhancement.

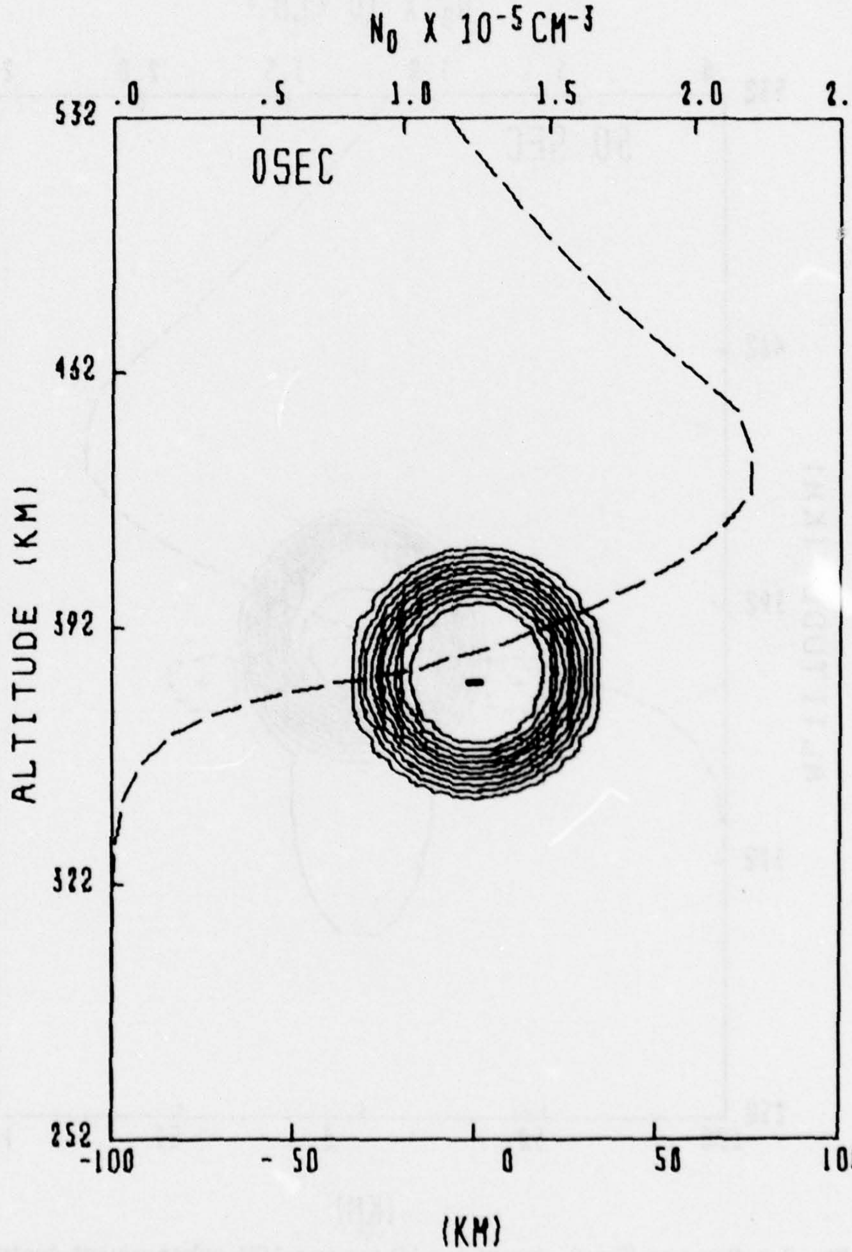

Fig. 6 — Same nomenclature as Figs. 1 and 2, except new simulation with n_o profile raised so peak is now at 434 km (note difference in y axis) and t = 0 sec.

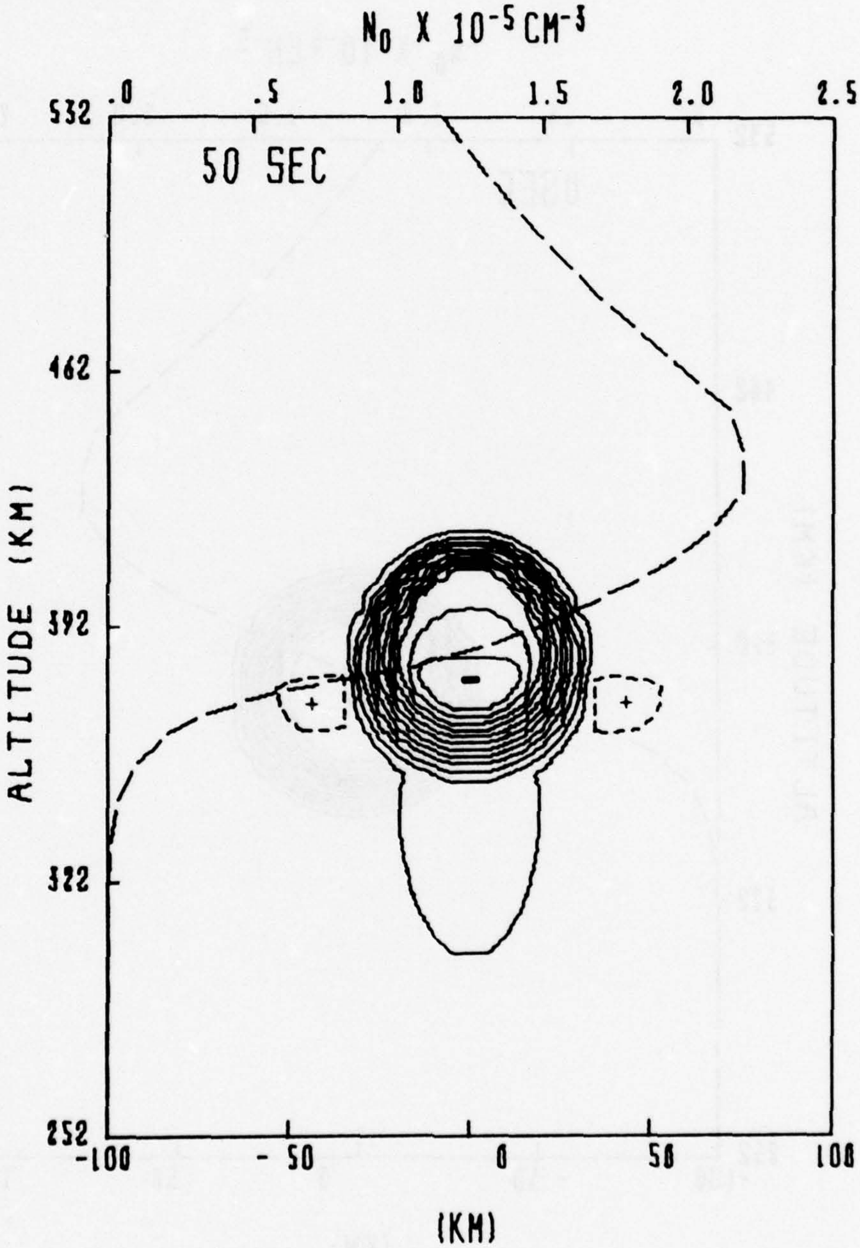

Fig. 7 — Same as Fig. 6, except t = 50 sec and 19% enhancement contours

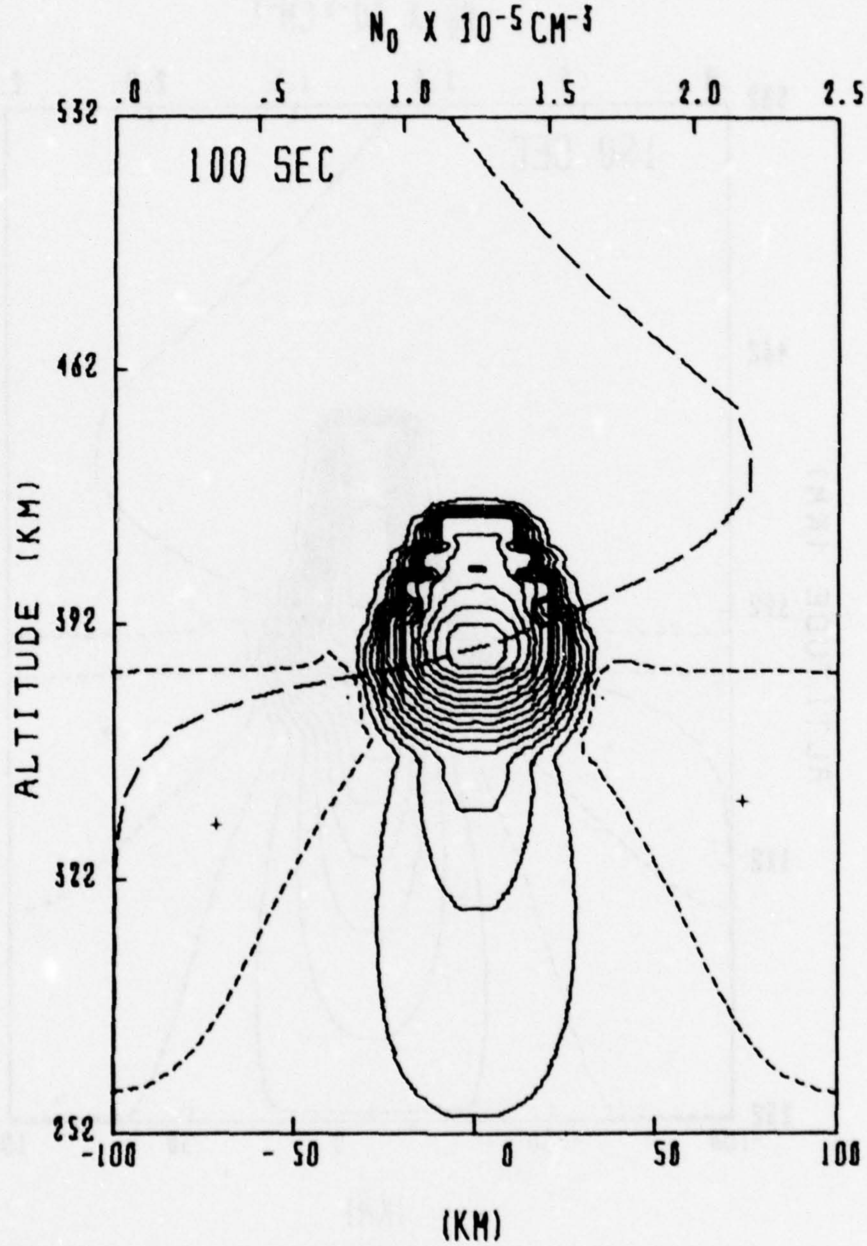

Fig. 8 — Same as Fig. 6, except t = 100 sec

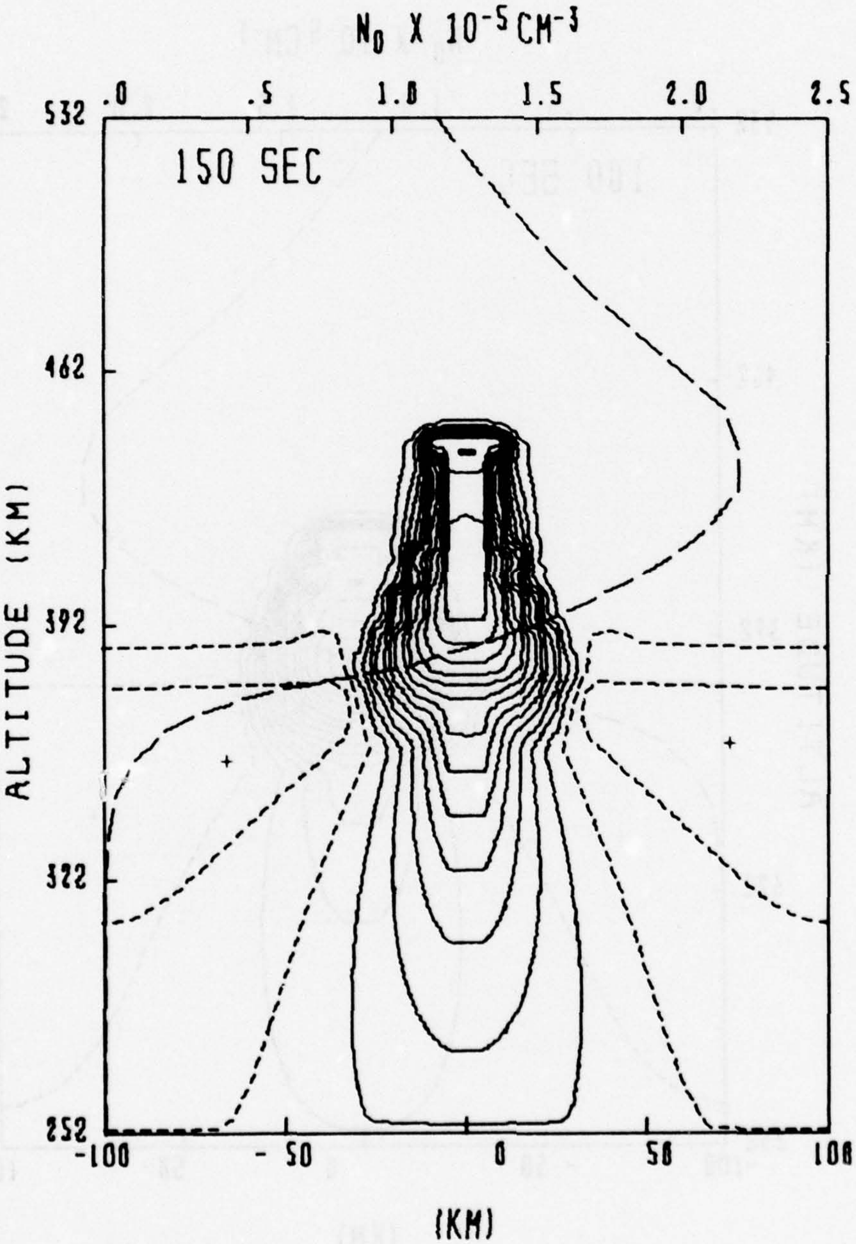

Fig. 9 — Same as Fig. 6, except t = 150 sec. and inner enhancement contour is 68%

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